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I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002951784 for a patent by CALLIDAN INSTRUMENTS PTY LTD as filed on 26 September 2002.

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PROVISIONAL SPECIFICATION

Invention Title: "MOISTURE ANALYSER"

The invention is described in the following statement:

TITLE

"MOISTURE ANALYSER"

FIELD OF THE INVENTION

THIS INVENTION relates to a moisture analyser. In particular, a moister analyser using microwaves for detecting moisture content and ultrasonics for determining material depth of an item located on a conveyor belt.

BACKGROUND OF THE INVENTION

On-line analysis for total moisture of a material is critical to enable a process technician and/or plant operator to optimize processes for a wide range of applications, such as dust suppression, process control, achieving product specifications and material handling.

Measurement of moisture content using microwaves has been investigated for many years. Moisture measurement using microwave methods are based upon a relatively high dielectric constant of water in comparison to a dielectric property of a material to be analysed. When a microwave signal passes through the material, some of the signal is absorbed such that the amplitude (ie. power level) of the microwave signal is less at a receiver than that transmitted. An amount of attenuation of this signal is related directly to the dielectric constant of the analysed material.

To illustrate this method, common sand (silicon dioxide) has a dielectric constant of 4.2 and water has a dielectric constant of 80.4. A variable amount of water within the sand results in a large variation in the combined dielectric constant of the sand and water, which is then

measurable by detecting a change in the microwave signal.

In addition to monitoring attenuation, velocity of the microwave signal is also effected by the dielectric constant of the material to be analysed with and without water. Increases in the dielectric constant slows the velocity of the microwave signal as it passes through the analysed material. This slowing is microwave velocity is proportional to a phase shift in microwave signal. Accordingly, velocity may be determined by measuring phase shift of the microwave signal.

Use of microwave technology to measure moisture content in a sample has advantages over many previous and outdated surface measurement techniques. Possibly the largest benefit of microwave methods is the fact that such a transmission method ultimately measuring about 80% of total material analysed. Apparatus are known that measure attenuation or phase shift of microwave signals at a several discrete discontinuous frequencies as discussed below.

GB 2,122,741 describes an apparatus for monitoring crushed coal. The apparatus monitors ash content and moisture content of the coal by respectively transmitting and detecting X-ray and microwave radiation. The microwave radiation amplitude is chopped at a low frequency of about 1.0 KHz which is suitable for analysing a crushed sample such as coal. However, this apparatus is not well suited for determining moisture content of other types of samples by on-line sampling methods.

US Patent No. 4,788,853 describes a moisture meter that also uses microwave signals at several discrete discontinuous frequencies,

preferably over a range from 4-8 GHz. This patent states that the number of frequencies required to perform the invention is not critical as long as sufficient data is generated.

AU 61689/90 describes an apparatus for determining moisture content in a sample of varying thickness on a conveyor belt. The microwave signals are transmitted at several discrete discontinuous frequencies within a selected range.

Although the above described apparatus may be useful for determining moisture content in a sample, these apparatus are nevertheless still are prone to substantial errors or inaccuracies due at least in part to variation in sample depth or configuration. Also, transferring microwave technology to an on-line situation such as a conveyor belt poses many challenges.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an alternative or improvement to the abovementioned prior art.

In a first aspect, the invention provides a moisture analyser comprising:

(i) means for generating a continuous linearly sweeping microwave signal varying in frequency;

(ii) means for transmitting the generated microwave signal;

(iii) means for receiving the transmitted microwave signal;

(iv) means for measuring attenuation of an amplitude of the received microwave signal and generating an output signal;

(v) means for measuring a depth of a sample exposed to the transmitted microwave signal, said means generating an output signal; and

(vi) means for processing the output signals from (iv) and (v) thereby determining moisture content of the sample located between the transmitted and received microwave signal.

The first aspect may further comprise a means for measuring a phase shift in the respective transmitted and received microwave signals of the continuous linearly sweeping microwave signal and generating an output signal to be received by the processor.

In a second aspect, the invention provides a moisture analyser comprising:

(a) means for generating a continuous linearly sweeping microwave signal varying in frequency;

(b) means for transmitting the generated microwave signal;

(c) means for receiving the transmitted microwave signal;

(d) means for measuring a phase shift in respective transmitted and the received microwave signals of the continuous linearly sweeping microwave signal and generating an output signal;

(e) means for measuring a depth of a sample exposed to the transmitted microwave signal, said means generating an output signal; and

(f) means for processing the output signals from (d) and (e) thereby determining moisture content of the sample located between the

transmitted and received microwave signals.

In a third aspect, the invention provides a method for determining moisture content in a sample including the steps of:

(1) generating a continuous linearly sweeping microwave signal varying in frequency;

(2) transmitting the microwave signal;

(3) receiving the transmitted microwave signal;

(4) measuring attenuation of an amplitude of the received microwave signal and generating an output signal;

(5) measuring a depth of a sample exposed to the transmitted microwave signal and generating an output signal; and

(6) processing the output signals from (4) and (5) to determine moisture content of the sample located between the transmitted and received microwave signals.

The third aspect may further include a step of measuring a phase shift in the respective transmitted and received microwave signals of the continuous linearly sweeping microwave signal and generating an output signal to be received by the processor.

In a fourth aspect, the invention provides a method for determining moisture content in a sample including the steps of:

(I) generating a continuous linearly sweeping microwave signal varying in frequency;

(II) transmitting the microwave signal;

(III) receiving the transmitted microwave signal;

(IV) measuring a phase shift in respective transmitted and the received microwave signals of the continuous linearly sweeping microwave signal and generating an output signal;

(V) determining a depth of a sample exposed to the transmitted microwave signal and generating an output signal; and

(VI) processing the output signals from (IV) and (V) to determine moisture content of the sample located between the transmitted and received microwave signals.

Preferably, for each of the abovementioned aspects, the continuous linearly sweeping microwave signal varies in frequency between a range of about 0.10 GHz to 4.00 GHz.

More preferably, the continuous linearly sweeping microwave signal varies in frequency between a range inclusive of 1.25 GHz to 1.65 GHz.

Preferably, in relation to any one of the abovementioned aspects, the phase shift is measured by a microwave mixer that receives a portion of the respective transmitted and received microwave signals and generates an output signal.

Preferably, the output signal comprises an oscillating voltage with a DC bias that is proportional to both a change in microwave velocity and phase shift.

Preferably, the means for transmitting and receiving the microwave signal are respective antennas.

Preferably, the attenuation of the amplitude and phase shift of

the microwave signal is measured by random stratified sampling.

More preferably, the random stratified sampling is performed using an algorithm within the processor.

Preferably, for each of the abovementioned aspects, the depth of the sample is measured by an ultra-sonic means.

Preferably, the processing is performed by a microprocessor.

Preferably the moisture content is determined by calculating predicted moisture content using the equation:

Moisture content = M0 +M1*(Attenuation/Depth of material) + M2*(Velocity/Depth of material)+M3*(Velocity/ Depth of material)^2 + M4*(Attenuation/ Depth of material)^2; wherein

Attenuation of amplitude = (amplitude measured with sample) - (amplitude measured without sample);

Microwave velocity = (velocity measurement with sample) – (velocity measurement without sample); and

Depth of Material = (Depth with sample) - (depth without sample); and

M0, M1, M2, M3 and M4 are calibration coefficients that are dependent upon an application.

It will be appreciated that the present invention provides an improved apparatus and method for measuring moisture content in a material (eg. a sample) by transmitting and receiving a continuous linearly sweeping microwave signal. The invention also provides a unique means of sampling the amplitude (eg. microwave power level) and phase shift (eg.

microwave velocity) by random stratified sampling such that errors introduced by varying bulk density and bed depth of the sample are less influential upon the result. Accordingly, accuracy of measured moisture content of a sample (crushed or uncrushed) may be improved by using the invention.

The linear sweeping microwave measurement cycle ensures that the measurement is in fact continuous and no material within the analysis zone goes unmeasured. Accordingly, the invention is suitable for on-line applications such as analyzing moisture content of samples moving on a conveyor belt.

Throughout this specification unless the context requires otherwise, the word "comprise", and variations such as "comprises" or "comprising", will be understood to imply the inclusion of the stated integers or group of integers or steps but not the exclusion of any other integer or group of integers.

DESCRIPTION OF THE DRAWINGS

In order that the invention may be readily understood and put into practical effect, preferred embodiments will now be described by way of example with reference to the accompanying drawings wherein like reference numerals refer to like parts and wherein:

FIG. 1 shows a general configuration of an embodiment of the invention;

FIG. 2 shows a schematic diagram of the invention; and

FIG. 3 is a graph showing prediction of moisture content using

the apparatus of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an apparatus for measuring and estimating "free" moisture content within a material. In one embodiment, the apparatus is used to measure a material located on and moving along a conveyor belt. "*Free*" moisture content as used herein means water molecules within a material that are able to rotate freely within the material. "*Inherent moisture content*" as used herein means the moisture content of material comprising water molecules that are not free to rotate within the material.

FIG. 1 shows a general representation of a moisture analyzer 10 comprising a transmitting antenna 11, receiving antenna 12, an ultra-sonic apparatus 40 (located behind receiving antenna 12) and a processor 30. A sample 21 located on a conveyer belt 20 is shown being analysed by analyzer 10. A white arrow shown on conveyer belt 20 on the bottom of FIG. 1 shows direction of movement of the conveyer belt 20 and sample 21 located thereon.

FIG. 1 at the top shows and end view of analyzer 10 transmitting a microwave signal 13 from transmitting antenna 11. The microwave signal is received by a receiving antenna 12 located above the sample 21. Ultra-sonic apparatus 40 is more clearly seen in the bottom part of FIG. 1 that shows a side view of the analyser 10 shown in the top part of FIG. 1. Ultra-sonic apparatus 40 is located behind receiving antenna 12 (ie. after receiving antenna 12 relative to direction of movement of the conveyer

belt 20). However, ultra-sonic apparatus 40 can alternatively be located in front of receiving antenna 12. An ultra-sonic signal 41 is shown as a double headed arrow. The ultra-sonic signal (eg. beam) measures sample bed depth. By measuring moisture content using the microwave signal and sample bed depth using the ultra-sonic signal, a percentage of moisture content can be determined. The processor 30 is a microprocessor capable of receiving outputs from respective components of the moisture analyser 10 as described in more detail hereinafter. Processor 30 is located within an electronics control cabinet 32 that comprises a local display and keypad for operator interface.

FIG. 2 shows a schematic representation of an embodiment of the moisture analyser 10 comprising a microwave generator 14, transmitting antenna 11, receiving antenna 12, ultra-sonic apparatus 40, moisture amplitude detector 15, microwave mixer 31 and processor 30. Also shown in FIG. 2 is a transmitted signal shown as a continuous linearly sweeping microwave signal that varies in frequency inclusive from 1.25 GHz to 1.65 GHz in a "saw tooth" pattern. Continuous linearly sweeping signal refers to frequency variations (ie. sweep) through a predetermined frequency range. As shown in FIG. 2, a continuous linearly sweeping signal appears as a "saw tooth" pattern sweeping through a range inclusive of 1.25 GHz to 1.65 GHZ. This is distinct from a discontinuous signal that refers to one or more discrete single frequencies, for example, 1.0 GHz, 1.2 GHz and 1.4 GHz. The continuous linearly sweeping signal varying in frequency provides the advantages over moisture analyzers that measure only a discrete single

frequency as described herein. FIG. 2 further shows a received signal as measured attenuation of amplitude (ie. microwave power level) by Random Stratified Sampling. As discussed herein, a phase shift in microwave signal may also be measured using Random Stratified Sampling. Additional benefits of measuring by Random Stratified Sampling include improved accuracy of estimating actual free moisture content as discussed below

The moisture analyzer 10 comprises a microwave generator 14 that is capable of generating a continuous linearly sweeping microwave signal of varying frequency. Preferably, the frequency is varied between about 0.10 GHz to 4.00 GHz. However, a more preferred frequency range is inclusive of 1.25 GHz to 1.65 GHz. The microwave signal repeatedly cycles within a selected range, for example, increasing from 1.25 GHz to 1.65 GHz then decreasing to 1.25 GHz and so on in a "saw tooth" fashion as shown in FIG. 2. Microwave sweep generators known in the art would be suitable for use with the moisture analyzer 10, including for example, a klystron source, a Gunn diode or preferably a YIG source (ie. a Yttrium Iron Garnet crystal). The generated microwave signal is sent to the transmit antenna 11 as shown in FIG. 2.

A limitation of previous microwave analysers using attenuation is that they use set frequencies, or a number of discrete frequencies. The inventor has discovered that these known methods are less accurate due at least in part to a changing bulk density and thickness of the sample being measured. The present invention is an improvement over these known analysers by transmitting a continuous microwave signal that is linearly

sweeping.

The moisture analyser 10 has two (2) antennas 11 and 12; however, more than two (2) antenna may be used. A transmitting antenna 11 is located below sample 21 shown on conveyor belt 20. Transmitting antenna 11 transmits a microwave signal that is capable of passing through sample 21 and conveyor belt 20. A receiving antenna 12 is located above the sample 21 for receiving the microwave signal transmitted by transmitting antenna 11. It will be appreciated that the location of transmitting antenna 11 and receiving antenna 12 can be other than shown, for example the locations can be reversed. The location of the antennas need only be such that the transmitting antenna 11 can transmit a microwave signal through the sample 21 and the receiving antenna 12 can receive the transmitted microwave signal after passing through the sample 21. However, the distance of the transmitting antenna 11 is preferably close to the sample 21, such that the distance is less than the wavelength of the microwave signal. The antenna 11 and 12 can be any suitable antenna, for example horn antenna and dielectric rods as are known in the art.

The moisture analyzer 10 also comprises a moisture amplitude detector 15 capable of recording amplitude (eg. power levels) of the microwave signal received by receiving antenna 12. Suitable moisture amplitude detectors include those known in the art, for example, detector log video amplifiers DLVA. The amplitude is then transmitted to processor 30 as shown in FIG. 2.

The amplitude is not recorded in a continuous fashion, but rather is preferably recorded by Random Stratified Sampling. Random Stratified Sampling is a process of sampling randomly between regular intervals. This is preferable to even time based sampling as unpredictable periodic effects can be eliminated. By using this sampling method an effect of signal reflection and superimposing, which is a result of varying bulk density and depth of material, can be reduced by a factor of 5.

Signal reflection and superimposing in relation to the present invention relates to when a microwave signal is transmitted into a dense medium (eg. sample), some of the microwave energy is reflected, some absorbed and some transmitted. The transmitted signal is measured for determining moisture content. However, the reflected signal can interfere with the signal that is being transmitted from the transmitting antenna. This interference can take a form on annulling or superimposing the transmitted signal. This is undesirable and a problem that is evident with early microwave moisture analysers that used a single frequency or discrete frequencies. By linearly sweeping the transmitted microwave signal over a broad bandwidth (eg. range of frequencies) and also sampling the signal using the Random Stratified Sampling technique, errors introduced by signal reflection and superimposing can be reduced. This is a major improvement and novel approach compared to previous methods using discrete frequencies.

An ultra-sonic apparatus 40 measures and records a depth of the sample 21. This ultra-sonic signal is also transmitted to the processor 30. Ultra-sonic apparatus that are known in the art are suitable for use with

the invention, for example a Miltronics "Probe". Other methods for measuring sample depth may be used, for example nuclear digital density gauges. However, the ultra-sonic apparatus 40 is preferred.

A sample located between the transmitted and receive microwave signals (eg. between the transmitting and receiving antenna) will change the velocity of the received signal. This change in the received velocity when compared with the transmitted signal (which typically remains substantially constant) will cause an output of mixer 31 to also change as discussed below. The output of the mixer 31 is measured and this output is proportional to the change in dielectric constant between the antennas. It will be appreciated that velocity and phase shift are directly proportional to each other, accordingly either may be measured.

Microwave velocity may be determined by microwave mixer 31 that measures a phase shift in the transmitted and received signal. Commercially available microwave mixers such as, Marki type mixers, are suitable for use with the invention. Microwave mixer 31 receives a portion of the transmitted and received microwave signals and provides a measure of microwave velocity by measuring a phase shift in the respective signals. Microwave velocity is calculated by measuring the change in the output of the mixer. The output of the mixer is an oscillating voltage. By measuring the DC bias of this oscillating voltage, a measure of the change in velocity or phase shift can be determined. The change in this DC bias is proportional to the change in velocity of the transmitted microwave signal and hence provides a measure of the change in the overall dielectric constant of the

material between the two antennas 11, 12. This signal is then transmitted to the processor 30. This DC bias can also be measured using the Random Stratified Sampling method.

Moisture analyzer 10 is well suited for detecting moisture content of a sample 21 moving on a conveyor belt 20 because microwave signals can be transmitted continuously through the sample 21 as it moves along the conveyor belt 20. Accordingly, if the moisture content varies in the sample 21, an error in detecting moisture content is reduced. Although moisture analyzer 10 in a preferred embodiment is used to detect moisture content in a sample moving along a conveyor belt, moisture analyer 10 can also be used to measure moisture content in a stationary sample. The sample can be any suitable sample that is substantially transparent to microwave signals. The sample can have a varying thickness or a constant thickness. The sample may be crushed (eg. as for coal) or uncrushed. Conveyor belt 20 is substantially microwave transparent and may be made of a material such as a synthetic plastic, including polypropylene, polyvinyl chloride. Conveyor belts for minerals (eg. coal) may have a PVC layer laminated with a wear resistant layer, such as chlorinated polyethylene or "Neoprene"®.

Moisture content of sample 21 can be estimated using the moisture analyzer 10 by measuring attenuation of microwave amplitude (eg. power level) and ultrasonic bed depth. Moisture content can also be estimated by measuring microwave velocity, which affects a phase shift, and ultrasonic bed depth. Further, moisture content can also be determined by

measuring microwave attenuation, microwave velocity and ultrasonic bed depth, which in some applications may improve accuracy of determining moisture content.

Measuring Attenuation, Velocity and Sample Depth

Measurement (in dB) of the power level (ie. amplitude) of both an empty conveyor belt and a sample laden conveyor belt is used to derive attenuation of microwave power level caused by the sample, which is being analysed.

Attenuation of amplitude = (Power level measured on laden belt) - (Power level measured on empty belt).

Like wise the measurement of respective velocities of an empty conveyor belt and a sample laden conveyor belt is used to derive a change in velocity caused by the sample being analysed.

Microwave velocity = (Laden belt velocity) – (Empty belt velocity).

The depth of material upon the conveyor belt is measured by subtracting the depth of a sample on a laden belt from depth of an empty belt. Depth of material is estimated using an ultra-sonic measuring apparatus.

Depth of Material = (Depth of material on a laden belt)-(depth of material on a empty belt).

Calculating Moisture Content

The following equation is used to predict moisture content in a sample.

Moisture content = M0 +M1*(Atten/Depth of material) + M2*(Velocity/Depth of material)+M3*(Velocity/ Depth of material)^2 + M4*(Atten/ Depth of material)^2

Where M0, M1, M2, M3 and M4 are calibration coefficients that are dependent upon an application. These values could be determined by performing a simple linear regression of the variables against a laboratory determined moisture value as is common in the art.

In order that the invention may be readily understood and put into practical effect, particular preferred embodiments will now be described by way of the following non-limiting examples.

EXAMPLE 1

Apparatus Set-up and Typical Results

Apparatus Set-up and Assessment

The moisture analyser as described in FIGS. 1 and 2 is used for determining the moisture content within a known bulk material. The analyser is left to stabilise after power-up for a period of 1 hour for heated enclosures to reach a stable temperature (this provides stability for the microwave components). The output of the microwave ("M/W") attenuation of amplitude, velocity, and ultrasonic bed depth are transferred to a standard industrial type Programmable Logic Controller (PLC), where by the results are recorded from the appropriate addresses. Any suitable PLC common in the art may be used.

M/W attenuation, velocity, and ultrasonic bed depth is measured for an empty conveyor belt.

A sample of material is placed onto a running conveyor. For a period of 15 minutes the average M/W attenuation, velocity, and ultrasonic bed depth are measured. During this same period a sample of the material is taken from the moving conveyor and sent to a laboratory for the measurement of % Total Moisture.

The following values are used:

Attenuation (atten) of amplitude = (M/W attenuation upon laden conveyor)-(M/W attenuation upon empty conveyor belt)

Microwave velocity = (M/W velocity upon laden conveyor)-(M/W velocity upon empty conveyor belt)

Bed Depth = (ultrasonic bed depth upon laden conveyor)-(ultrasonic bed depth upon empty conveyor belt)

Approx 15 samples were taken over a varying moisture range for calibration. The following data is data obtained by a simulated trial.

Results

The data set is shown below and graphically in FIG. 3

Table 1

Lab % Moist	Attn	Velocity	Bed depth	Atten/Bed depth	Velocity/ Bed depth	Gauge Predicted Moisture
0.29	1.354	8782.2	604	0.002241722	14.54006623	0.279
0.29	1.452	8782	602	0.00241196	14.58803987	0.313
0.35	1.5649	8786	598	0.00261689	14.69230769	0.351
0.41	1.71	8787	597	0.002864322	14.71859296	0.401
0.47	1.89	8789	601	0.003144759	14.62396007	0.464
0.53	2.08	8790	620	0.003354839	14.17741935	0.528
0.59	2.25	8791.3	598	0.003762542	14.70117057	0.589
0.65	2.438	8792.5	601	0.004056572	14.62978369	0.653
0.71	2.614	8792	604	0.004327815	14.55629139	0.713

A simple linear regression was carried out using the three (3) measurements taken by the abovementioned apparatus and correlated with the Laboratory moisture value. The regression data is shown below.

Regression output

Table 2

	Regression Output:	
Constant		0.475187
Std Err of Y Est		0.011373
R Squared		0.995924
No. of Observations		9
Degrees of Freedom		6
X Coefficient(s)	208.117	-0.04554
Std Err of Coef.	5.469494	0.024566

Whereby the gauge predicted moisture is calculated using the following equation.

Moisture content = M0 +M1*(Atten/Depth of material) + M2*(Velocity/Depth of material)+M3*(Velocity/ Depth of material)^2 + M4*(Atten/ Depth of material)^2

In this case the following values were used.

M0 = 0.475
M1 = 208.117
M2 = -0.04454
M3 = 0
M4 = 0

It is understood that the invention described in detail herein is susceptible to modification and variation, such that embodiments other than those described herein are contemplated which nevertheless falls within the broad scope of the invention.

The disclosure of each patent and scientific document, computer program and algorithm referred to in this specification is incorporated by reference in its entirety.

DATED this Twenty-sixth day of September 2002

CALLIDAN INSTRUMENTS PTY LTD

By their Patent Attorneys

Fisher Adams Kelly

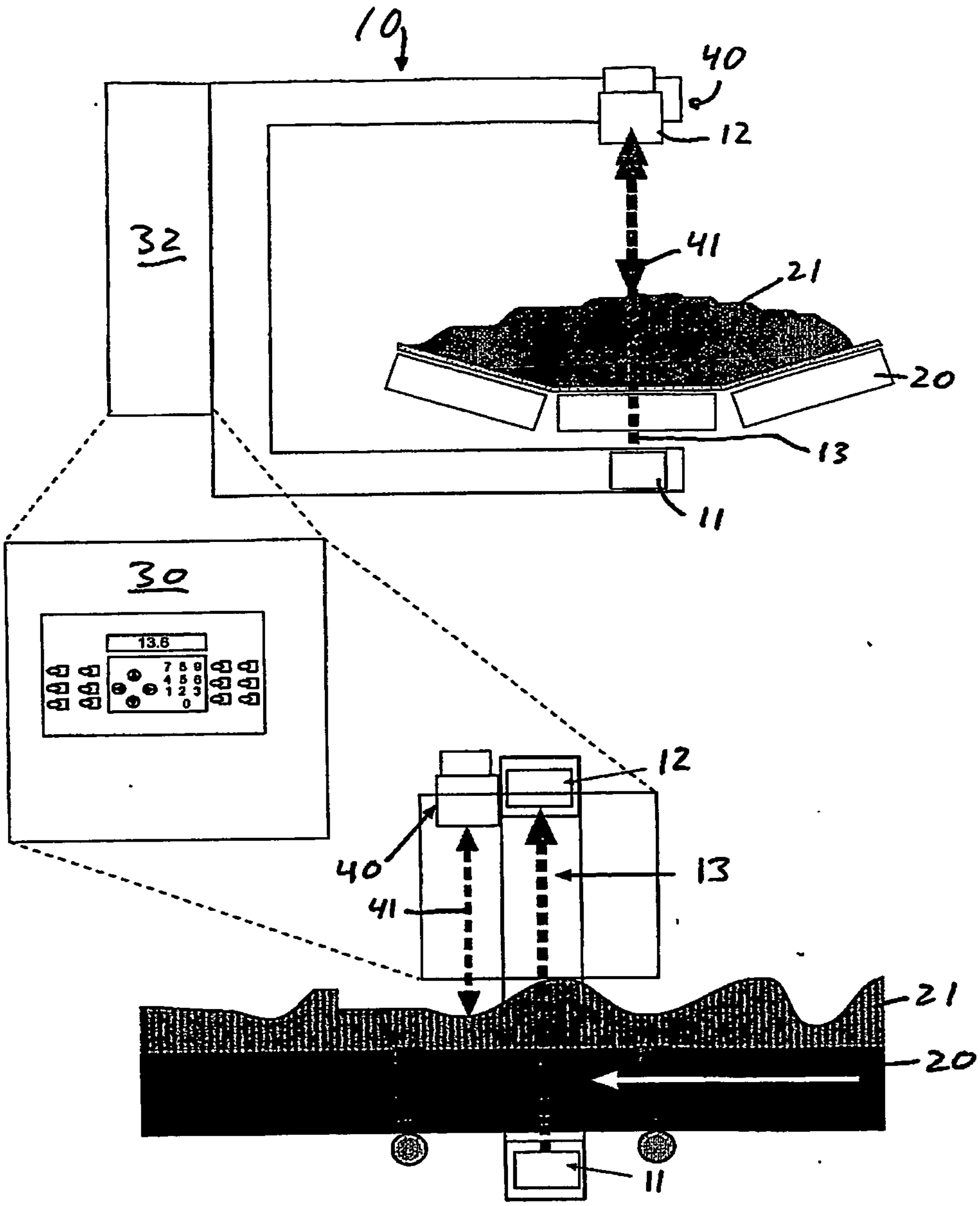

FIG. 1

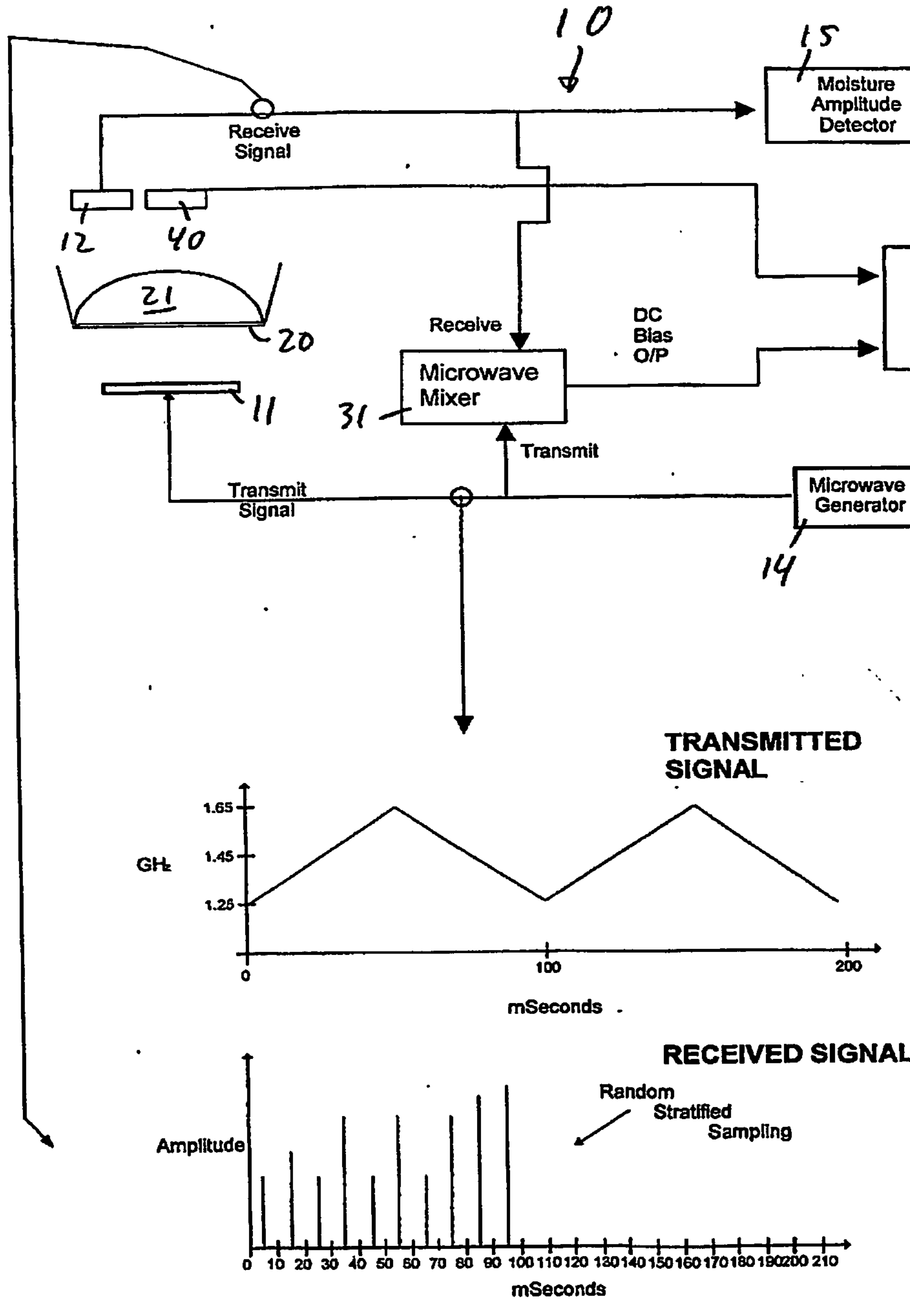
10
15
Moisture Amplitude Detector
Video O/P
Receive Signal
12
40
21
20
Processor
30
Receive
DC Bias O/P
Microwave Mixer
31
11
Transmit
Transmit Signal
Microwave Generator
14
TRANSMITTED SIGNAL
GHz
1.65
1.45
1.25
0
100
200
mSeconds
RECEIVED SIGNAL
Random Stratified Sampling
Amplitude
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
mSeconds

FIG. 2

Prediction of moisture content using the above appartus

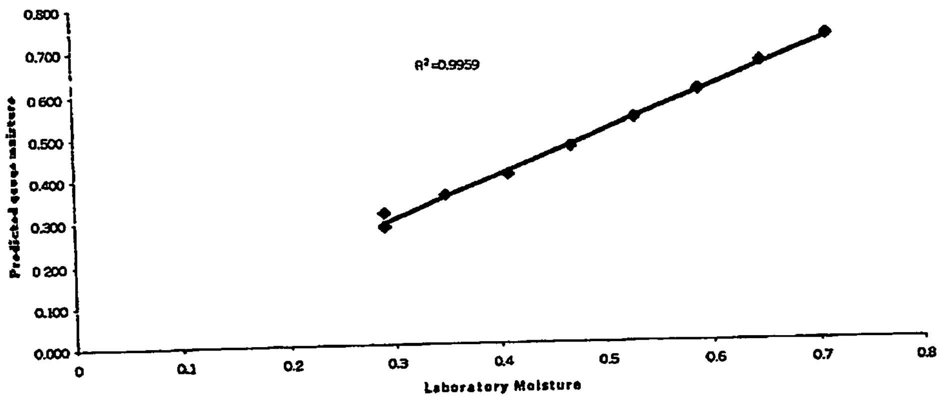

FIG. 3